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Influence of land tenure interventions on human well-being and environmental outcomes

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Land tenure security is increasingly recognized as a foundational element for advancing global sustainable development agendas, but questions remain about how it affects human well-being and environmental outcomes. We identify 117 studies that aimed to estimate the causal effect of land tenure security interventions on these outcomes. Approximately two-thirds of these studies reported positive links between improved tenure security and human well-being or environmental outcomes. Close to half of the studies that examined social and environmental outcomes reported positive impacts on both. The majority of studies assessed government-implemented interventions that statutorily recognized rights through land titling and formalization in the 1990s and 2000s. More research is needed to bolster the body of evidence on the effects of non-technical interventions (for example, capacity building and awareness raising) and the devolution of rights to inform future land policy efforts and accelerate sustainable development.

With nearly half of the world's population living in rural areas of low- and middle-income countries, policymakers increasingly recognize that clear, secure and equitable access and rights to land are foundational for strengthening land governance systems, social stability, economic growth, environmental conservation and human development[1,2]. As a result, land tenure security (LTS) has increasingly gained prominence with the rise in global sustainability agendas, such as the Paris Agreement and the United Nations Sustainable Development Goals, as many of these agendas now articulate both human well-being and environmental targets. Yet, globally, the effect of LTS on human well-being and environmental outcomes is still uncertain. For example, evidence on the role of land rights for achieving desired climate goals remains "established but incomplete"[3]. Given the prominent role of LTS in global sustainability agendas, understanding its relationship to human well-being and environmental conditions is essential. These two outcomes are jointly important precisely because they are the central metrics by which a diverse set of sectors judge various sustainability goals.

Contemporary land tenure insecurity often stems from colonial imprints of property systems that were established for extractive purposes to benefit colonial settlers[4]. These systems were usually carried over by post independence governments, making legal pluralism the reality for most of the world[5]. Recent policies to strengthen LTS, such as decentralization[6], often have goals of clarifying or enforcing existing tenure arrangements[7,8], or ameliorating historical power imbalances through interventions to empower women[9,10] and indigenous groups[11], often through titling and formalization[12–14].

In general, policies that strengthen LTS to advance sustainability goals are based on the assumption that recognizing rights will benefit the landholder by 'unlocking' capital (for example, by providing access to credit or by enabling full utilization of production factors), reducing uncertainty[15,16], providing opportunities and empowerment, and incentivizing the sustainable use of natural resources[17] (see Supplementary Information). These rationales have fuelled substantial investments in policies that depend on LTS to achieve their goals, with over US$2.5 billion spent on land titling efforts alone in the past two decades (https://www.aiddata.org/). The confluence of interests that seeks to strengthen LTS highlights the urgency of understanding the state of knowledge, to guide both research and sustainability policies.

In the past three decades, there has been a notable increase in assessments of interventions that address LTS (Supplementary Fig. 1). This emerging body of work has given rise to several reviews of LTS that examined its impacts on deforestation[18], women's rights[19,20], agricultural investment[21,22] and food security[23] (Supplementary Table 1). The study that is closest to the present work examined the social and environmental outcomes of LTS across 36 qualitative and 23 quantitative studies (although they were affiliated with a particular donor agency and their search yielded a smaller set of studies)[24]. However, these existing reviews focused on specific geographies, biomes, interventions or outcomes, which prevent a

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broader perspective on how the existing evidence supports the various policy efforts.

Building on these previous efforts, we review 117 quantitative studies that attempt to isolate the causal relationship between LTS interventions and human well-being or environmental outcomes (see the methods described in the Supplementary Information). We do not limit our search to geography, biome, intervention type or outcome. Using categories developed by the International Fund for Agricultural Development (IFAD) and the Global Land Tool Network (GLTN)[25], we define tenure interventions as distinct efforts (policies or programmes) that aim to strengthen the LTS of the landholder. Using Kaplan-Hallam and Bennett's human well-being framework[26], we examine any outcomes that would fall within social, cultural, economic, health and governance domains. We aggregate and summarize the evidence for how LTS interventions affect human well-being and environmental outcomes, uniquely track temporal aspects of intervention studies, and catalogue changes in land tenure characteristics pre and post intervention. We find that interventions that enhance LTS are, on average, associated with positive human well-being and conservation outcomes, although the effects are not universal. We also find that the existing literature focuses heavily on land ownership formalization and titling, which results in crucial gaps in understanding the impacts of other types of intervention (such as capacity building, awareness raising and devolution of rights).

Results

Characteristics of studies reviewed. We identified 117 studies that estimated the causal impact of tenure interventions on human well-being and environmental outcomes (Methods and Supplementary Fig. 2). The studies included those with causal study designs (for example, randomized controlled trials (RCTs) and instrumental variables), counterfactual techniques (for example, difference-in-differences (DiD) models), or control and comparison groups. We excluded studies that focused exclusively on urban communities. The methodological, geographical and intervention characteristics of our selected studies are shown in Fig. 1a.

Of the 117 studies, 54 (46%) were of 'high rigour' (for example, the RCT and DiD studies) in that they analysed panel data sets and included a counterfactual or control group (Fig. 1a, top, column 6). Of these, 33 studies identified the counterfactual groups with statistical matching (Fig. 1a, top, column 1), and 34 used DiD models. We found four published assessments of RCTs.

There was high geographical and demographic variation among the studies in this analysis. The studies covered 42 countries, with overrepresentation from Ethiopia and China (Fig. 1b). The number of studies meeting our inclusion criteria increased by year (Fig. 1a, bottom, column 1), which suggests broad advances in methodological standards. Working landscapes, usually agricultural lands, were the predominant landscape type (96 studies, 82%), followed by forests (28 studies, 24%) and grasslands or wetlands (3 studies, 2.6%) (Fig. 1a, bottom, column 2). Almost all of the studies (104 studies, 89%) examined the effects of LTS on agricultural households (Fig. 1a, bottom, column 3), and most of the studies (81 studies, 69%) included a gender analysis (Fig. 1a, bottom, column 4).

The study duration (the years between the baseline and the post-intervention measurements) and the duration of the exposure period (the years after the intervention) were closely correlated with the type of assessed outcomes (Supplementary Table 4). The duration of the studies varied widely, ranging from 1 to 75 (ref. [27]) years (median 8 years) (Fig. 1a, bottom, column 7). Studies that evaluated only environmental outcomes typically had longer study durations (median 11 years) than those that evaluated only human well-being outcomes (median 7 years). Seventy-eight studies (67%) assessed interventions that were implemented between 1990 and 2009 (Fig. 1a, bottom, column 8). Half of these (39 studies) evaluated the effects of titling and formalization (such as when government-recognized land documentation had been issued), perhaps reflecting the rise of land titling efforts in the 1980s and their subsequent decline[28].

Studies predominantly focused on titling and formalization. We coded intervention types on the basis of the five intervention categories created by the IFAD and the GLTN[25] (Table 1): titling and formalization (for example, official rights recognition and boundary clarifications), planning (for example, land use planning), policy (for example, legal or policy reforms), capacity building (for example, administrative capacity building), and awareness raising (for example, land rights literacy campaigns). Fifty-seven studies (49%) evaluated efforts that used more than one kind of intervention (Fig. 1a, bottom, column 6). Formalization programmes were by far the most commonly assessed tenure intervention (70 studies, 60%). Studies in Ethiopia, China, Peru and Vietnam together represented more than half of these formalization programmes (37 studies, 53%). Forty-nine studies evaluated the impact of issuing state-recognized land documents to landholders, with the most commonly studied policies being Ethiopia's land certification programme (11 studies), Peru's *Programa Especial de Titulación de Tierras* (7 studies), and Vietnam's *Đổi Mới* land reform programme (7 studies). The remaining formalization efforts clarified property rights and boundaries, or increased land access for marginalized or vulnerable groups. Changes in land use planning and management, commonly in conjunction with either policy reforms or land rights clarification and formalization, were the second-most common intervention (49 studies; 42%). Interventions that involved capacity building of land administration offices and awareness raising of land rights received less attention (7 and 5 studies; 6 and 4%, respectively).

Government agencies were the most common organization to implement interventions (84 studies, 72%) (Fig. 1a, bottom, column 5), and primarily aimed to increase LTS through titling and formalization, land redistribution, or by introducing statutory laws to protect marginalized populations or the environment. In 18 studies (15%), interventions were managed by government agencies with implementation support from intermediary organizations, such as civil society or private sector organizations. These collaborative cases mainly focused on providing land access or formalizing land rights, with only three studies looking at the devolution of rights or the recognition of customary tenure regimes. Only three studies (2.6%) in our review evaluated interventions implemented by non-governmental organizations, and these interventions involved the devolution of rights to communities and/or the strengthening of their capacity to manage land. Only two studies (2%) assessed interventions led by communities (for example, the rural shareholding cooperatives in China facilitated land distribution and access[29]).

Studies mostly assessed de facto to de jure tenure changes. Tenure insecurities are often resolved by the formalization of land rights, a process whereby the state formally recognizes (and documents) previously informal ownership, access or trade of land resources[30]. This process confers rights from a de facto, or customary, status to a de jure, or legal, status recognized by a governing authority. For each study, we recorded whether the rights were recognized statutorily ('de jure') or customarily (or in practice; 'de facto'). When rights in practice (de facto) and rights by law (de jure) were aligned, so that there was no gap between formal and informal tenure, we denoted the case as 'de jure + de facto'. Thus, we recorded which of these three contexts applied to a study at both the baseline (pre-intervention) stage and again at the post-intervention stage: de jure (legally defined rights), de facto (socially defined rights) and de jure + de facto (rights that exist both legally and socially).

Given the substantial multilateral efforts to formalize property rights, we might expect most studies to have evaluated the move from de facto to de jure + de facto rights, or studies that conducted

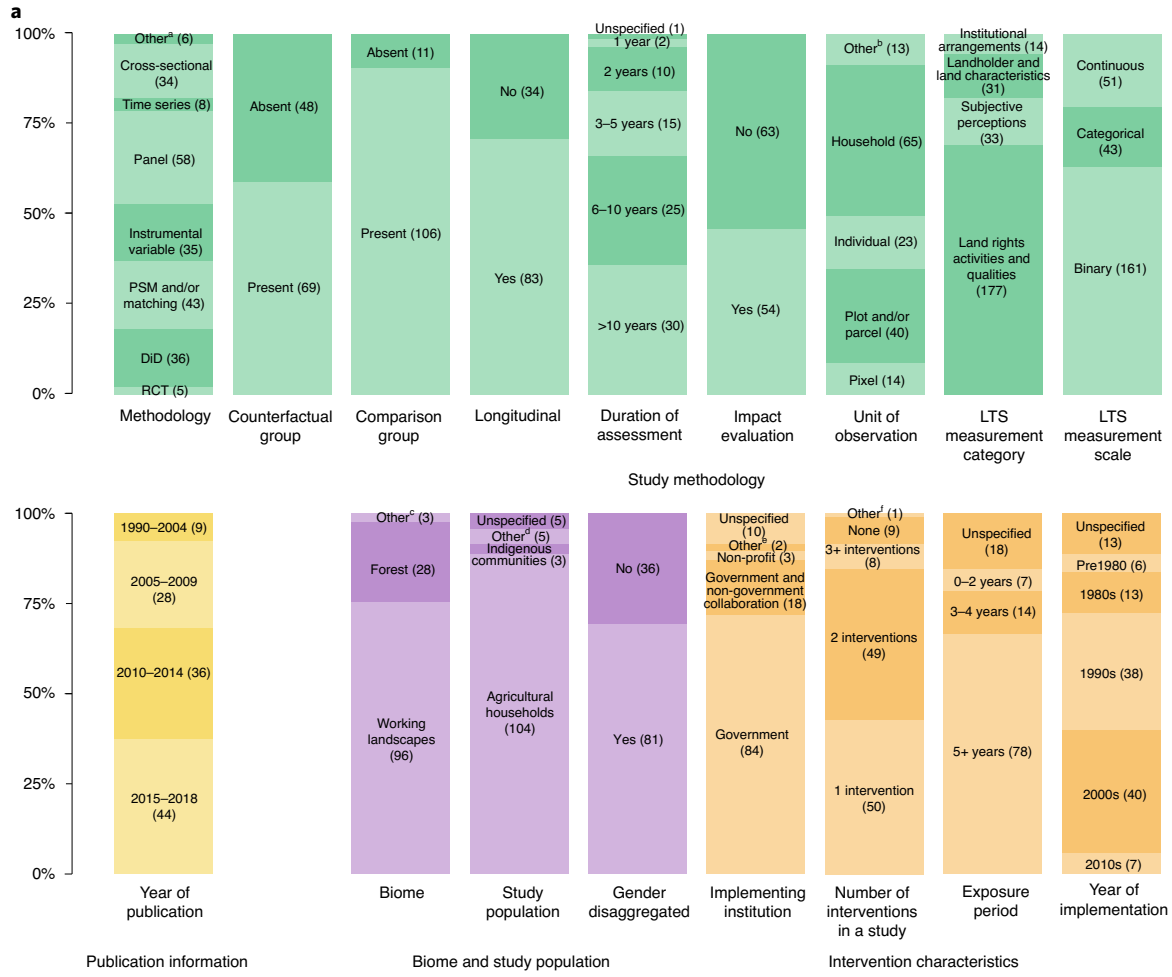

Fig. 1 | Global distribution and characteristics of the studies and land tenure interventions included in this analysis. a, Characteristics of the studies and interventions. Numbers in parentheses indicate the number of studies for all of the characteristics coded, except for the LTS measurement category and the LTS measurement scale. For these two characteristics, numbers in parentheses indicate the number of variables out of a total of 255 variables. Some studies fell into more than one category for a characteristic (including characteristics such as biome, methodology and unit of observation). A study was coded as having a counterfactual group if it employed RCTs, before-after-control-impact, DiD, PSM or statistical matching, or regression discontinuity designs. Studies were coded as having a comparison group if there was a clearly identified group that received no treatment, an alternative treatment, treatment of a different intensity, or a group that received treatment at a different time point. To meet our inclusion criteria, a study needed to have either a counterfactual or a comparison group. Supplementary Table 2 provides a detailed description of superscripts a–f. **b**, Global distribution of studies, colour-coded according to the number of studies for each country. PSM, propensity score matching.

Table 1 | Categories of land tenure security intervention inputs evaluated by studies reviewed

Intervention type	Included interventions	*n*	Assessed human well-being outcomes (*n*)	Assessed environmental outcomes (*n*)
Titling and formalization	Clarification of landholders' property rights and boundaries, official recognition of de facto rights, land access	70	61	26
Planning	Land use planning and natural resource management	49	31	28
Policy	Legal, regulatory and policy dialogue; advocacy and reform at government administration levels	42	29	17
Capacity building	Capacity building of offices in land administration, planning, valuation and conflict resolution	7	6	4
Awareness raising	Awareness raising (literacy) of land rights and regulations	5	4	2
Other	Land tenure insecurity as a result of invasions	1	0	1

Fifty-seven studies (49%) combined different intervention types. As a result, the total sample size (*n*) exceeds the 117 reviewed papers. Categories of intervention type and included interventions are from the IFAD and the GLTN[25].

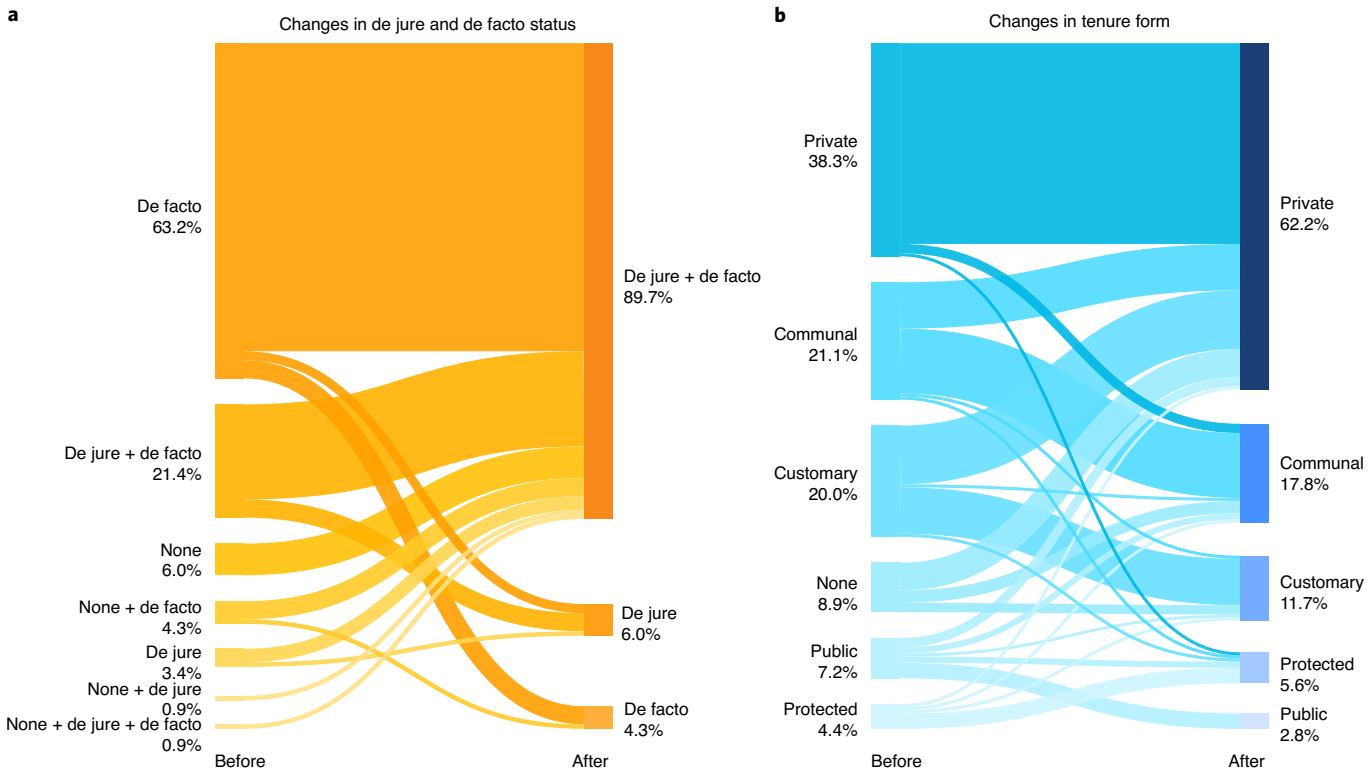

Fig. 2 | Changes in de jure and de facto tenure status and in tenure form before and after interventions of the studies reviewed. a, Proportion of studies in which the recognition of rights was de jure, de facto, or both, before and after an intervention. Proportions are of the 117 studies reviewed. 'None' indicates the study populations that were landless or land poor, sometimes in combination with populations that had de jure and/or de facto status. **b**, Proportion of cases in which land tenure form (that is, whether land is public, protected, customary, communal, private or 'none') transitioned between the baseline and after the intervention. Proportions are of the 180 transition cases from the 117 studies reviewed.

cross-sectional analyses to have compared one group with de facto rights against another group with de jure + de facto rights. Indeed, at baseline, most situations were characterized as de facto (74 studies, 63%) and only one-fifth were characterized as having both legal and social tenure, or de jure + de facto (25 studies, 21%) (Fig. 2a). Post intervention, almost 90% of the studies (105 studies) were characterized as de jure + de facto, which reflects a predominant focus on formalization. All landless or land-poor populations (Fig. 2a, 'none') (14 studies, 12%) gained de facto and/or de jure status, most often through a redistribution of the land and/or the provision of formal titles. Naturally, it was less common (6 studies, 5%) for interventions to assign de jure rights without also aligning de facto rights (that is, changing from de facto to only de jure, or from de jure + de facto to just de jure) (Supplementary Table 6). This could happen, for instance, if a new inheritance law gave women inheritance rights, but the law was not fully enforced and recognized within communities[31]. Still

fewer studies (3 studies, 2.6%) investigated interventions that aligned de facto rights with pre-existing de jure rights to ensure that communities were aware of and enforced the rights that existed by law. These three studies investigated land boundary demarcations. Tenure status remained unchanged in almost a quarter of studies (26 studies, 22%). These 26 studies focused on contrasting populations with different levels of existing LTS resulting from local or customary practices, or were cases that sought to strengthen LTS without formalizing land rights (for example, by conducting awareness campaigns about property rights[32]).

Studies largely assessed land privatization. In addition to looking at the de facto and de jure status of land tenure, we separately considered land tenure form (that is, whether land is private, communal, customary, public or protected). We recorded transitions of land tenure form before and after interventions. In cases where a study assessed multiple forms or had instances of overlapping tenure forms, such as when private land is embedded within a protected area, we coded each transition type separately, resulting in 180 transition cases from the 117 studies.

Shifts in tenure form reflect the dominant transition toward privately held land (Fig. 2b). While private land was the most prevalent at baseline (69 cases, 38%), post-intervention private land had increased to 62%. Communal and customary lands (38 and 36 cases; 21% and 20%, respectively) were the next most common baseline conditions, and both of those categories either stayed the same or became private landholdings post intervention. All landless cases (16 cases, 9%) transitioned to some form of tenure, and nine of these cases became private land. Most cases in protected areas (5 out of 8 cases from baseline) did not transition to other categories. Post intervention, customary and public tenure forms saw the largest decreases (42% and 61% fewer cases than at baseline, respectively).

In total, 47 cases (26%) had a change in tenure form to private land (Supplementary Table 7). Some shifts to private lands focused on specific marginalized populations. For instance, 10 of the 19 cases that recorded shifts from customary tenure to private tenure examined the recognition of women's land rights through joint titling and inheritance law reform. Fifteen cases examined privatization of community lands, of which ten examined de-collectivization in China, Vietnam and Eastern Europe. Nine cases assessed the effects of provisioning private land to landless and land-poor populations through land allocation and redistribution programmes. Only one case focused on privatization of a protected area, in which formal rights were granted to squatters in forest reserves[33].

Compared with de jure and de facto rights, most cases showed no change in tenure form (111 cases, 62%). Of the 111 cases with no change in tenure form, 65 examined populations that had private land pre and post intervention. Of these 65 cases, 44 cases involved formalization efforts (that is, providing de jure recognition for private landowners who already had de facto status), and four cases involved the loss of de facto rights by private landowners as a result of threats of land expropriation. The other 46 cases examined situations in which landowners had varying strengths of rights (for example, those who owned versus those who rented land) but with the same tenure form (private), or were cases in which LTS improved without a change in tenure form (for example, land boundary clarifications, capacity building and education programmes).

Land tenure security largely led to positive outcomes, but trade-offs existed. We report the distribution of effects in three categories: studies that assessed the impact of LTS on human well-being outcomes, studies that assessed the impact on environmental outcomes, and studies that assessed the impact of LTS on both outcomes together.

Human well-being outcomes were assessed in 92 studies (Fig. 3a and Supplementary Table 8). Economic aspects of human well-being (for example, access to credit, participation in land rental markets, and land productivity) were the most common (70 studies) and were generally positively associated with LTS interventions. Studies that evaluated outcomes related to governance (24 studies) largely used subjective perceptions of land security, with mostly positive impacts, although some studies showed no clear direction of effects. Fewer studies assessed other governance-related outcomes evaluating common property resources or access to public goods and services, and the direction of impact was mixed. Other socially related outcomes were evaluated in 21 studies, most of which examined women's empowerment (for example, women's participation in household decisions). Women's empowerment was examined across nine countries (Ethiopia, Kenya, Rwanda, Tanzania, Zambia, India, Nepal, Vietnam and Peru), and the distribution of effects indicates strong support for the positive effects of LTS (72% positive). We found little consistent support for LTS improving other social outcomes (such as interpersonal disputes, investment in education, land-related attitudes and knowledge). Health-related outcomes were assessed in just 11 studies, all of which looked at family planning and food security. Two-thirds of the studies on food security reported positive links to improved LTS.

Forty-eight studies evaluated the effects of LTS on environmental outcomes (Fig. 3b and Supplementary Table 8), and most of these focused on agricultural practices, such as soil and water conservation (23 studies). Other outcomes included changes in biophysical or ecological indicators such as natural forest conditions (19 studies), investment in agroforestry (11 studies), and investment in forest conservation (6 studies). About two-thirds of these studies reported positive effects. Proxies for biodiversity received less attention; only two studies were found on this topic, one on land abandonment[34] and another on tree species and primate populations[35]. Given that the effects of LTS on biodiversity outcomes are understudied, the overall impact is difficult to assess.

In aggregate, more studies found positive impacts on human well-being and environmental outcomes than found negative or unidentified impacts, combined. Of the 92 studies that assessed human well-being outcomes, 82% included at least one positive outcome, 14% included at least one negative outcome, and 45% contained unidentified effects. Of the 48 studies on environmental outcomes, 73% showed positive effects, 15% had negative outcomes, and 29% had cases in which no effect was identified. These proportions were roughly reflected in the subset of studies that examined both types of outcome (23 studies) (Fig. 3c). After stratifying outcomes from all studies on the basis of intervention types, we found that the distribution of effects for the three most commonly assessed interventions (land formalization, planning and policy) also reflected similar distributions (Supplementary Table 9). Six studies evaluated capacity-building interventions and reported positive effects on human well-being. However, this was not reflected in the effects of capacity-building interventions on environmental outcomes (three of four studies reported unidentified results). The effect of awareness raising on strengthening LTS was mixed for both types of outcome, with roughly equal proportions of positive, negative and unidentified impacts.

On examination of the subset of studies (23 studies) that jointly investigated the effects of LTS on human well-being and environmental outcomes (Fig. 3c), there were ten instances in which tenure interventions seemed to result in 'win–win' situations (Supplementary Table 10). Only one study on Zimbabwe's fast-track land reform programme reported a 'lose–lose' situation[36]. About half of the studies (12 studies) showed trade-offs and reported on some combination of both positive and negative impacts. In contrast to 'win–win' cases, these studies tended to have among the most rigorous research designs, and they evaluated interventions such as capacity building and awareness raising campaigns as opposed to land formalization and privatization. These studies also examined a

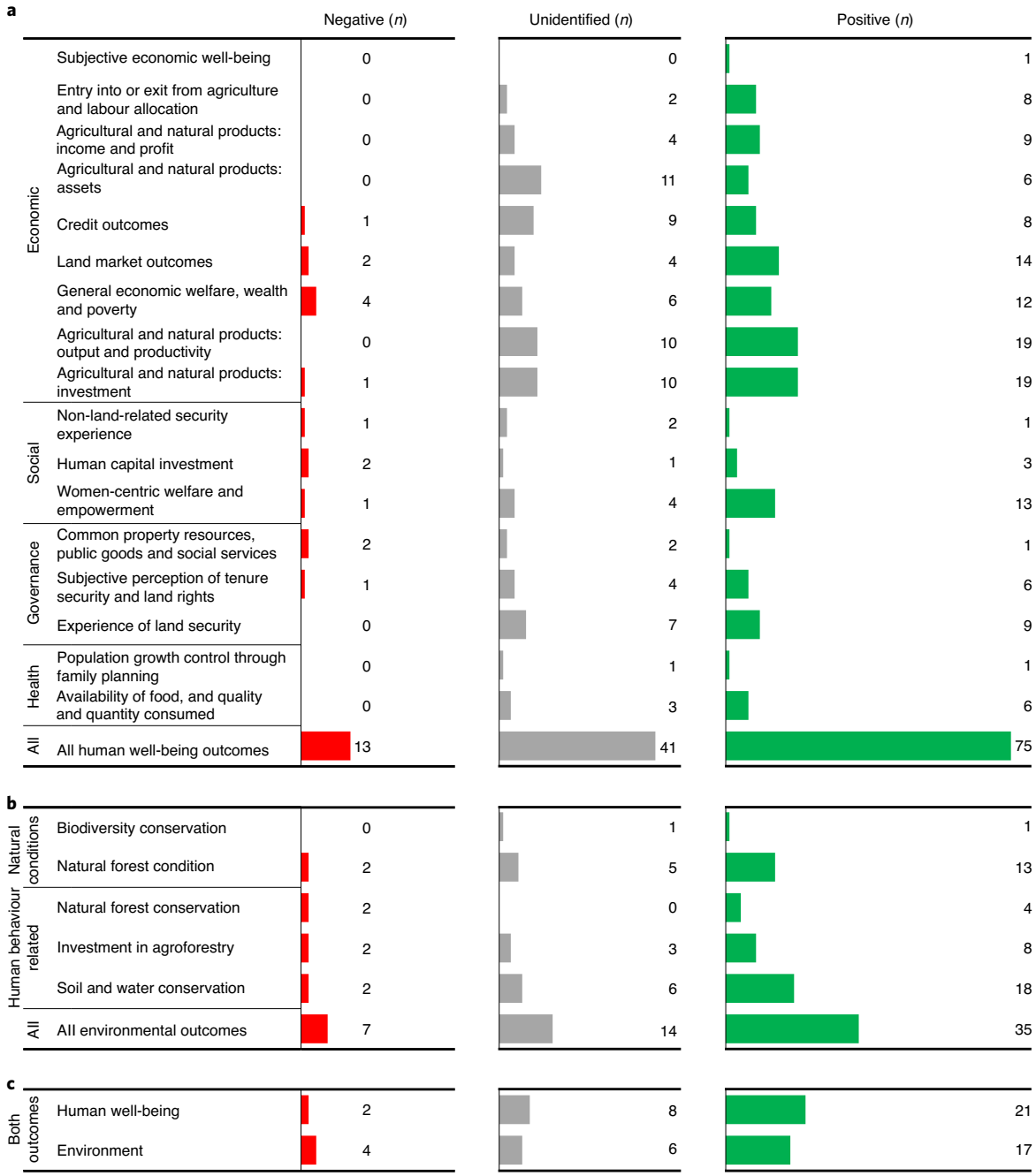
a
Negative (n)
Unidentified (n)
Positive (n)
Economic
Subjective economic well-being 0 0 1
Entry into or exit from agriculture and labour allocation 0 2 8
Agricultural and natural products: income and profit 0 4 9
Agricultural and natural products: assets 0 11 6
Credit outcomes 1 9 8
Land market outcomes 2 4 14
General economic welfare, wealth and poverty 4 6 12
Agricultural and natural products: output and productivity 0 10 19
Agricultural and natural products: investment 1 10 19
Social
Non-land-related security experience 1 2 1
Human capital investment 2 1 3
Women-centric welfare and empowerment 1 4 13
Governance
Common property resources, public goods and social services 2 2 1
Subjective perception of tenure security and land rights 1 4 6
Experience of land security 0 7 9
Health
Population growth control through family planning 0 1 1
Availability of food, and quality and quantity consumed 0 3 6
All
All human well-being outcomes 13 41 75
b
Natural conditions
Biodiversity conservation 0 1 1
Natural forest condition 2 5 13
Human behaviour related
Natural forest conservation 2 0 4
Investment in agroforestry 2 3 8
Soil and water conservation 2 6 18
All
All environmental outcomes 7 14 35
c
Both outcomes
Human well-being 2 8 21
Environment 4 6 17

Fig. 3 | Distribution of human well-being and environmental outcomes from the reviewed studies. Distribution of studies that reported positive, negative, or unidentified (no or undetermined) effects from studies that investigated human well-being outcomes ($n = 92$) (**a**), environmental outcomes ($n = 48$) (**b**), and both human well-being and environmental outcomes ($n = 23$) (**c**). A study may have examined more than one domain and outcome, or used multiple indicators to evaluate one category, therefore the total number studies in 'All' does not always equal column sums. Supplementary Table 8 provides descriptions of our categorization scheme, which is based on ref. [26].

greater number of human well-being outcomes and focused largely on changes in natural environmental conditions. Taken together, efforts to strengthen LTS generally contributed to improved human well-being and environmental outcomes, although, perhaps unsurprisingly, tenure interventions are not a silver bullet to societal problems.

Discussion

The elevated importance of LTS in sustainability agendas highlights an urgent need to better understand whether the existing evidence supports current and planned policy efforts. Our analysis helps to fill this gap by synthesizing the results from studies that cover a broad set of geographies, biomes, interventions and outcomes. Although publication and geographical bias could affect the distribution of effects of LTS [37–40], they reflect the best available evidence from the scientific and policy community. We found strong support that strengthening LTS is, on average, positively associated with human well-being outcomes, particularly through land formalization, land use planning and policy reforms. Efforts to formalize property rights (that is, titling programmes) in particular had a strong relationship

with economic outcomes on agricultural lands, broadly supporting findings from past reviews on similar topics[21,22,24,41,42]. We found positive but weaker support that strengthening LTS improves environmental outcomes, although this was mainly related to short-term land investments and management outcomes, and mostly over forest conditions. Evidence was limited for long-term effects on environmental outcomes, which are ultimately the environmental outcomes of interest. Therefore, it is important to consider more long-term effects of tenure security on land, biodiversity or ecosystem services. We also found some trade-offs between the impact of LTS on human well-being and environmental outcomes. In the subset of studies that assessed both outcomes jointly, 52% found negative or unidentified impacts on either social or environmental outcomes. For example, in the Republic of Congo, a study examining the implementation of sustainable forest management-based policies that increased LTS found an increase in legal timber production, but also higher deforestation rates[43]. Although only a few studies jointly examined social and environmental outcomes, these are important for understanding social-ecological system dynamics. New measurement technologies, such as remote sensing and communication technologies, that reduce the cost of monitoring and evaluation should make integrated evaluation studies more feasible in the future.

Our analysis highlights several knowledge gaps and additional data needs. First, although a wide range of geographies and demographic groups were represented in our study set, several countries are overrepresented (for example, Ethiopia and China, in which the state is always the formal landowner), and this may colour our understanding of the impacts of tenure security. Many studies also focused on agricultural communities, so our analysis may have limited external validity among nomadic, pastoralist, indigenous and other populations; those living in understudied biomes such grasslands and wetlands; or those involved in emerging but important issues (for example, small-scale artisanal miners[44]). Given our search approach, we may have missed some newer or locally focused studies. Many studies lacked information on measurement contexts, such as distributional impacts (that is, impacts on inequality) and spatial aspects of land that might affect or mediate tenure (for example, relationships between plots, land attributes and land prices[45]).

Second, most studies examined titling or formalization programmes, perhaps reflecting general trends in implementation[12,13], but also potentially because titling is, in general, a 'cleaner' intervention to evaluate (that is, individuals either receive or do not receive title). The emphasis on titling programmes leads to several issues, including knowledge gaps for other interventions, such as the devolution of rights, information campaigns, conflict resolution and strengthening the governance of customary systems. Indeed, large efforts such as the 'reducing emissions from deforestation and forest degradation-plus' (REDD+) often rely on strengthening tenure security through non-titling interventions. The focus on titling also underlies widespread use of land title as a proxy for tenure security despite a growing literature arguing that title should not be equated with tenure security[18,46]. Furthermore, although conceptually simple, titling programmes often involve the resolution of long-held land disputes and can be fraught with political challenges that are ultimately unsuccessful due to multiple challenges[47]. Sometimes, these interventions have little effect on a population's perceived security, even if the programme was 'successfully' implemented. For instance, customary rights may be sufficiently secure in some areas, and titling or formalization may have little effect on perceived LTS.

Third, our analysis revealed that few studies examined changes in longer-term environmental conditions, such as changes in biodiversity. Extrapolating short-term effects on environmental outcomes may not always be appropriate, as increased LTS may also lead to intensified agriculture, which could have longer-term negative environmental effects. Such temporal dynamics are rarely studied. More work is also needed to articulate the indirect impacts of strengthening LTS and recognize its role in complex systems. In agricultural settings, for instance, LTS may improve land management, leading to improved soil quality, and then to greater food security and farm income, but can also increase nutrient runoff from intensification. LTS can confer benefits to landholders in ways that provide them voice, such as enabling 'defensive environmentalism' when land becomes subject to external pressures[48]. A better understanding of the causal pathways through which LTS operates may be especially important for the support of biodiversity conservation programmes and, in general, the sustainable use of natural resources.

Less than half of the studies (54 studies, 46%) met the most rigorous impact evaluation criteria of having both a counterfactual group and covering more than one time period, indicating opportunities to advance knowledge through more rigorous research designs. Our analysis also found that many studies examined programmes that involved more than one intervention, and in some cases, involved more than one implementing actor. This can create several challenges for evaluating evidence supporting the efficacy of LTS interventions, as studies may oversimplify interventions, miss synergies unique to a combination of interventions, miss implementation challenges, and may have difficulty estimating the marginal contribution of each actor or intervention. We organized interventions into tidy categories, potentially masking the on-the-ground reality and politics that shaped, motivated or otherwise mediated the effectiveness of most LTS interventions.

There is broad consensus that LTS is foundational for sustainability on a crowded planet. Most, though not all, investments in LTS result in positive social and environmental impacts. LTS affects many land-based decisions and provides opportunities to leverage capital, invest in livelihood opportunities, or improve land and housing quality characteristics that relate to health and well-being. Despite this, we still have a poor understanding about the returns on investing in tenure relative to other policy or investment alternatives, as well as the conditions under which LTS interventions lead to positive impacts. Future impact evaluations and studies should help to fill the geographical, thematic and programmatic gaps in our knowledge and to better understand the dividend on LTS investments. Any new evidence should be disseminated to practitioners and policymakers to maximize evidence-informed policies[49].

Methods

Our goal was to identify empirical studies that estimated the causal effect of interventions to strengthen LTS on human well-being and environmental outcomes in low- and middle-income countries. To do so, we employed a standard review protocol. Our protocol built on previous review efforts that examined the effects of LTS[22,24,50]. Each stage of the review framework was reviewed by all authors.

Selection criteria. We predefined inclusion criteria for the populations, interventions, comparators, outcomes and study designs for the literature reviewed, following PICO protocol standards[51,52]. We looked for studies conducted in low- and middle-income countries[53] (as classified at the time when these studies were conducted) that assessed the human well-being of rural populations and environmental outcomes in relation to interventions that alter the security of their land tenure and property rights. We targeted quantitative studies that used plausible causal identification strategies with counterfactual or comparison groups and assessed human well-being or environmental outcomes with data at the subnational scale.

We included studies that accounted for the counterfactual scenario and evaluated changes in human well-being or environmental outcomes over time. These methods identify the causal impact of tenure interventions by accounting for other time-invariant unobservable characteristics of the study population that might affect outcomes of interest[54–56]. We deemed a study to be a counterfactual case when the study design used an RCT, a before-after-control-impact design, a DiD approach, or a statistical (for example, propensity score) matching techniques. We also included studies that had comparison groups, which are clearly identified groups that receive no treatment, an alternative treatment, a treatment of a different intensity, or a treatment at a different point in time. Although these studies with comparison groups that adjusted for confounders are not as robust

at drawing causal inference about longitudinal studies with counterfactuals, they provided broader insights about the effects of tenure interventions and tended to yield similar results[57,58].

Search strategy. We conducted our search in Scopus, ProQuest and the Web of Science on the same day and with the same search strings. Our search strings looked for studies that included land, tenure interventions and impact evaluation terms (see the Supplementary Information for our exact search strings and filters, and their iterations) in the title, abstract and keywords. We used exclusion terms related to urban and peri-urban settings and environmental impact assessments. We limited our search to research articles written in English and published after 1990. We supplemented our database search with other published studies and grey literature included by authors of past reviews[18,20–22,24], as well as other studies identified by the authors of the present work. All bibliographic references were stored in the citation management software EndNote (version X8, Clarivate Analytics).

Screening. The database search yielded 1,761 publications. After deleting 392 duplicates, we conducted abstract screening by two reviewers (B.E.R. and Y.J.M.), using the Rayyan software platform, and included studies if they met the criteria discussed above in their abstracts. This first step narrowed our database to 113 studies. We then conducted a full text screening by reviewing the entire text to ensure that the studies met the above criteria and included human well-being or environmental outcomes. This resulted in 62 studies. We supplemented our literature catalogue with 49 other studies from five reviews[18,20–22,24], and six studies from expert guidance that met our inclusion criteria. In the end, 117 original studies published between 1990 and May 2018 were included in the final set of studies that we reviewed. A flow diagram was constructed to show the search and screening process (Supplementary Fig. 2).

Coding. For each study, we extracted data on methodology, tenure interventions and contextual factors related to programme implementation, and human well-being or environmental outcomes. To ensure consistency of coding, T.-W.J.T. initially drafted all codes for the reviewed literature. To limit bias that may come with a single coder, the core analysis group (T.-W.J.T., B.E.R. and Y.J.M.) iteratively reviewed coding results during the coding process. Coding took place from June 2018 to June 2019, during which time the core analysis group reviewed results up to several times per week and approximately 100 times in total.

We first recorded the methodologies that a study employed in one or more of the following categories: RCT, before-after-control-impact, DiD, propensity score matching or statistical matching, regression discontinuity, instrumental variable approach, inverse probability weighting, panel data regression analysis, time-series method and cross-sectional regression analysis. We coded the year(s) of assessment and documented the unit of observation (if unstated, we used the description of statistical models or outcome data to determine the unit of observation).

We extracted all variables that measured some form of LTS from the main statistical or econometric analyses. LTS-related variables that were purely descriptive, or that were exclusively used for calculating propensity scores, developing matching groups, considering time or geographical effects, or conducting robustness checks were excluded. We assigned LTS variables into the following four measurement categories: institutional arrangements, landholder and land characteristics, subjective perceptions, and land rights activities and qualities. Institutional arrangements refer to formal and informal institutions that influence land use rights. Landholder and land characteristics refer to exogenous features of landholders or land that might differentially influence LTS or interventions. Subjective perceptions refer to the perceptions of study participants of their own LTS, including predictions of current and future tenure status and land rights. Land rights activities and qualities refer to enforcement and governance of land tenure interventions or policies and landholders' adoption and experience of land rights. We coded whether the measurement scale was binary, categorical or continuous.

We recorded the types of land tenure intervention and other tenure-related contextual factors. We first created open-ended codes for tenure interventions to capture nuances in programme implementation. In cases in which studies were unclear or contained multiple interventions, we coded what appeared to be the main land tenure comparison(s). Following the categories developed by the IFAD and the GLTN[25], we categorized interventions according to five groups of land tenure intervention types: (1) legal, regulatory and policy dialogue, advocacy and reform; (2) property rights and boundaries clarification, official rights recognition and access to land; (3) capacity building of land administration and of conflict resolution offices; (4) awareness raising (or literacy) of land rights and regulations; and (5) land use planning and natural resource management. We then coded the number of intervention(s) in each study. We also added a category for other types of intervention, which included studies that compared pre-existing differences in land rights rather than an explicit programmatic intervention. We extracted the type of organization implementing the intervention (for example, a government or a non-profit organization), the year the intervention was implemented, and the period of exposure to the intervention. The exposure period was calculated by using the year of assessment for cross-sectional studies and the last year of assessment for longitudinal studies. We further coded study population characteristics, whether women were identified separately in the sample, the study location, and the predominant biome type (prior to intervention) using the habitat classification scheme of the International Union for Conservation of Nature[59].

We recorded tenure rights status as a combination of the following categories: de jure, de facto, and none (for landless populations) on the basis of the intended objectives of the interventions and the study descriptions. De jure refers to formal, legally recognized tenure status, whereas de facto refers to non-legally recognized or enforced tenure status and perceived land security. We considered customary laws as de facto unless studies mentioned that they were formally recognized by the state using a statutory law. A study at one point may have more than one tenure rights status in association with more than one tenure form (for example, private land in a protected area with de jure and de facto tenure arrangements).

We then coded whether tenure interventions were associated with changes in tenure form and tenure rights status. We classified tenure form before and after interventions according to the following categories: public, protected, customary, communal, private, and none (that is, landless). When there were instances of multiple tenure types (for example, communal and public land) or overlapping tenure forms (for example, indigenous communities living in protected areas), we separated all tenure types and coded transitions separately to capture the heterogeneity of tenure forms and transitions. A single study may therefore describe one or more tenure transition cases. Although the distinction between customary and communal is not always distinct in the literature, we described tenure forms as customary when studies described traditional customs influencing local tenure practices (for example, gender bias in land rights) and as communal when studies broadly described land being under collective or communal ownership. Additionally, literature from countries such as Ethiopia and China often emphasized that land is owned by the state, or that collective and rural households have only usufruct rights to land for a certain amount of time. Although the bundle of rights of private ownership in this context is more restricted relative to private land under less authoritative governance, government entities in other countries also tend to have the ultimate control over private land, even if not explicitly discussed, and we therefore grouped them together. Cross-sectional studies that used comparison groups were coded as not having a transition (that is, pretreatment and post-treatment tenure categories are the same).

Last, we recorded the directionality of the impacts of tenure interventions on human well-being and environmental outcomes. We categorized whether each human well-being and environmental outcome had improved (positive impact), deteriorated (negative impact), or remained unchanged or was unidentified (no or undetermined impact) for the more secure tenure condition relative to the less secure tenure condition. We focused on extracting main effects and left out subgroup effects, as the latter are often surreptitiously reported or exploratory, with sample sizes that are often too small to provide conclusive evidence. When a study used multiple methods to estimate marginal effects, we extracted results from the most robust causal inference method.

As an example, Deininger et al.[60] assessed the impacts of land certification on the perceived tenure security of farm households, rental market participation, and investment in soil and water conservation in Ethiopia. They used household- and plot-level panel data collected from 1999 to 2007 and estimated the effect of the policy using a DiD model. We coded variables measuring land certification and perceived tenure security in the LTS measurement categories 'Land rights activities and qualities' and 'Subjective perceptions', respectively, both on binary scales. Prior to the intervention, landholders held de facto usufruct rights to land, and women were described as being marginalized in the customary tenure system. Implemented by the Ethiopian government in 2003, the intervention issued use rights certificates to rural households that emphasized joint land ownership by including both spouses on certificates. This programme therefore falls under the intervention type 'property rights and boundaries clarification, official rights recognition and access to land'. We categorized the pretreatment tenure form as customary and private with de facto status, and the post-treatment tenure form as private with both de jure and de facto status. This resulted in two tenure-form transition cases: customary to private, and private to private. Relative to households that had not received certificates, those that did receive certificates perceived their land to be more secure (a governance-related human well-being outcome), participated more in the rental market (an economically realated human well-being outcome), and invested more in soil and water conservation (an environmental outcome). In this case, all the outcomes were coded as positive.

Analyses. We summarized coded information on study characteristics, land tenure interventions, and their contexts by calculating the number and/or proportion of studies corresponding to each variable of interest. For most summary statistics, a publication was our unit of analysis. In instances in which a study contained multiple types of variables (for example, a study with multiple biome types, study methodologies, units of observation, implementing institutions, interventions, and tenure form transition cases), we either created categories to capture multiple data points so that the denominators would be the total number of relevant studies, or we calculated the number or proportion of studies (or cases for tenure form) pertaining to each variable category so that the denominators would be the total number of data points for that variable.

For outcome data, we calculated the number of studies that examined first human well-being outcomes, then environmental outcomes, and then both. We assigned each coded outcome a category and a direction. A study may have assessed multiple outcomes relating to more than one category. We created our categories to maximize the resolution of outcomes seen in the land tenure literature. We further grouped human well-being categories into domains defined by Kaplan-Hallam and Bennett[26] to identify gaps in outcome assessment in the land tenure literature. While a study may have measured the same category using multiple indicators and found the same direction of results, we collated them and only kept one category–direction combination for each study. If there was disagreement, we kept all outcomes relating to the same category but included the different directions of results. We tabulated the number of studies reporting positive, negative, or unidentified outcomes. For studies that investigated both human well-being and environmental outcomes, we calculated the number of studies that reported jointly positive ('win–win'), negative ('lose–lose'), or trade-offs (win–lose or undetermined) in outcomes.

We performed all quantitative analyses and visualizations in Microsoft Excel, R (version 3.6.1), QGIS (version 3.12.3), and SankeyMATIC[61].

Data availability

The data sets generated and/or analysed during the current study are available on reasonable request.

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Author contributions

Y.J.M., B.E.R. and T.-W.J.T. designed the research. T.-W.J.T. collected, compiled and coded the data. Y.J.M. and B.E.R. reviewed data coding. Y.J.M., B.E.R. and T.-W.J.T. conducted the data analysis and synthesis. T.-W.J.T. wrote an initial draft of the paper, Y.J.M., B.E.R., M.F.B., A. BenYishay, A. Blackman, T.B., M.C., M.B.H., T.K., B.L., M.D., L.N., T.R., J.S., P.S., P.V., W.S. and W.Z. reviewed and revised the paper.

Competing interests

The authors declare no competing interests.

Additional information

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